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Inventory and growth predictions of the Petawawa Forest

G.M. Bonnor and S. Magnussen

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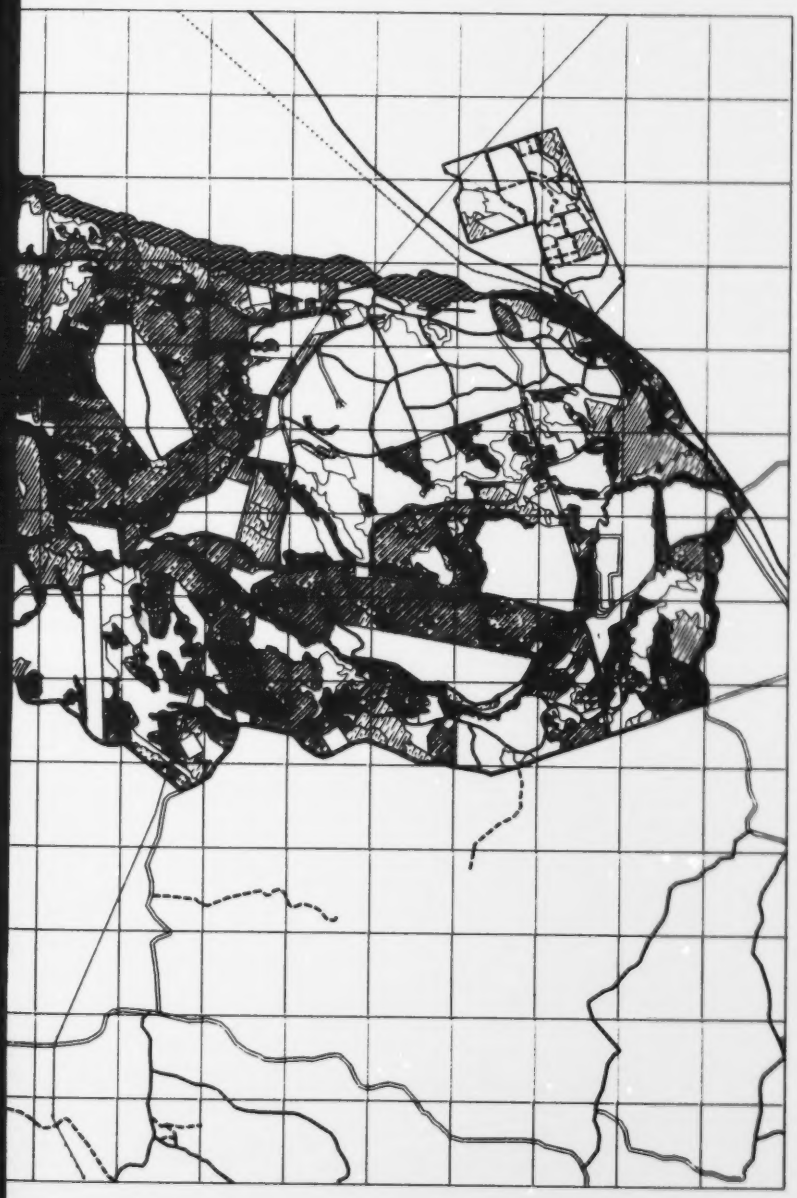
Petawawa National Forestry Institute



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Cover:

Petawawa National Forestry Institute
Managed Forest Area - Major Forest Types

INVENTORY AND GROWTH PREDICTIONS OF THE PETAWAWA FOREST

Information Report PI-X-66

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Abstract

A management type of forest inventory was completed in 1980 for a mixedwood forest area in the Ottawa Valley. The field sampling phase of the inventory was modified to permit the measurement of submerchantable trees and remeasurement of sample plots. This latter task was done in 1985.

The inventory data were used to compile area and volume estimates by strata, forest type, and other classifiers. The inventory data were also used with the 1985 plot measurements to predict future growth matrices, showing the growth (ingrowth, stagnation, or growth by 1 cm classes) or mortality of trees by stem diameter at breast height. The matrices were multiplied by 1985 stem diameter distributions to yield 1990 stem diameter distributions, which when multiplied by the matrices yielded 1995 distributions. The resulting values were used to derive volume and increment, by species, size classes, and other classifiers, for 1990 and 1995.

Results indicate that white pine (Pinus strobus L.) is the dominant species, with 35% of the 1985 volume of 210 m^3/ha. This dominance is expected to increase over the next 10 years, to 37%. The overall growth rate is expected to be 4.3 m^3/ha·yr or 2%, with white pine contributing almost half the growth.

Résumé

En 1980, un inventaire d'aménagement a été produit pour une étendue de forêt mixte de la vallée de l'Outaouais. La phase de l'échantillonnage sur le terrain a été modifiée pour permettre la mesure des arbres de taille non marchande et le contrôle des placettes d'échantillonnage. Ce contrôle a été effectué en 1985.

Les données de l'inventaire ont été utilisées pour la compilation des estimations de la superficie et du volume en fonction de la strate, du type forestier et d'autres critères de classement. Elles ont également été employées avec les résultats des contrôles effectués en 1985 pour établir des matrices de la croissance prévue indiquant l'accroissment (recrutement, stagnation ou croissance par classes de 1 cm) ou la mortalité des arbres en fonction du diamètre à hauteur de poitrine. Les matrices et les distributions du diamètre déterminées en 1985 ont été ensuite employées pour calculer, par multiplication, les distributions prévues du diamètre pour 1990, puis les distributions prévues pour 1995. Les valeurs obtenues ont servi à calculer le volume et l'accroissement prévus par espèce, classe de dimension, ou suivant d'autres critères de classment pour 1990 et 1995.

Les résultats indiquent que le pin blanc (Pinus strobus L.) est l'espèce dominante, constituant 35 % du volume, lequel s'élevait en 1985 à 210 m^3/ha. La dominance du pin blanc devrait augmenter au cours des 10 prochaines années et atteindre 37 %. Globalement, l'accroissement annuel devrait être de 4,3 m^3/ha ou de 2 %, le pin blanc en assurant près de la moitié.

INVENTORY AND GROWTH PREDICTIONS OF THE PETAWAWA FOREST

INTRODUCTION

There are many types of forest inventory used in Canada today, but the forest management inventory is the most prevalent and most important. It evolved in the 1950s in response to the need for better data on Canada's forest resources. It is unique in its use of air photographs, air photo interpretation, and complete stand mapping.

The forest management inventory is poorly named: the information it provides has been used primarily to exploit the forest. While this aspect is related mostly to the lack of any perceived need for forest management, it is also true that the inventory provides data of a static nature, i.e. quantities at a specific point in time. Such data are insufficient for good forest management. However, with fairly minor changes, the inventory can be used to collect data of a dynamic nature, i.e. data of changes in the forest.

One of the most important types of change is the growth of the forest: how big is the mean annual increment (MAI) or current annual increment (CAI)? How is the growth distributed among species, site classes, size classes, age classes, forest types, and among the stand growth components of ingrowth, survivor growth, and mortality? Answers to these and similar questions can frequently be deducted from analyses of changes in diameter distributions that are stratified by species and site classes. Stand volume and basal area can be calculated from the number of trees in each diameter class, which are also used to describe wood volumes by size classes and product categories.

The purpose of the study was to:

1) modify a forest management inventory to acquire growth data, implement the inventory, and document the methodology and results; and,

2) develop a computer-based model for predicting growth by diameter classes, implement the model using data from (1), and document the methodology and results.

Two inventory modifications were required, both related to the sample plots: first, at least some sample plots measured during the inventory had to be made permanent and remeasured and, second, data for small, submerchantable trees had to be obtained in each permanent sample plot (PSP). While these two changes were necessary for growth prediction, they were not sufficient for a complete inventory update. To do that, data on area changes had also be obtained and a new inventory system devised. Such a system is described by Bonnor and Magnussen (1986).

The growth model presented here is of a matrix type which accounts for trees within a given diameter class as they grow into larger classes or until they die. Our approach represents a mixture of new developments and the application of existing techniques.

THE FOREST

The inventory area is part of about 35 000 ha owned by the Government of Canada since 1904. Approximately 28% is occupied by the Canadian Forestry Service (CFS), the remainder by the Department of National Defence (DND). It is located about half-way between Ottawa and North Bay, or 35 km northwest of Pembroke, Ontario (Fig. 1).

The area lies on the southern edge of the Precambrian Shield which consists mainly of granite gneiss bedrock. Topography has been formed by glaciation and post-glacial outwashing. Physical features range from gently rolling hills of moderately deep loamy sand impregnated with boulders and broken rocks, to rough precipitous hills covered with thin sandy soil with frequent rock outcrops.

The climate is characteristically continental. Mean annual temperature is 5°C, and precipitation averages 780 mm (230 mm as snow). The frost-free period is 100 days and the growing season (number of days with temperatures higher than 5.6°C) is 185 days (Boughner 1964).

Effective fire suppression has kept losses due to fire at a low level. White pine blister rust has caused significant damage in the pine area, and substantial losses of balsam and spruce have been sustained over the last two decades due to spruce budworm epidemics.

The predominantly mixed, mature forest is located in the L.4C Middle Ottawa Section of the Great Lakes-St. Lawrence Forest Region (Rowe 1972). It is characterized by white pine (Pinus strobus L.), red pine (Pinus resinosa Ait.), trembling aspen (Populus tremuloides Michx.), and white birch (Betula papyrifera Marsh.). Red oak (Quercus rubra L.) and jack pine (Pinus banksiana Lamb.) dominate the drier and poorer sites. A complete list of the species, their common and botanical names, and their codes is given in Appendix 1.

The forest lands were first surveyed in 1917-20, and a forest map was prepared from the surveys in 1920. A 1925-31 strip cruise was summarized in 1933 and a working plan prepared. The area was also divided into blocks and compartments for management purposes. Growth data were collected at the same time, and a report (Anon. 1937) produced. A new forest map was produced in 1941 from 1939 air photos and used, with the preceding cruise data, to prepare a management plan (Bickerstaff 1948). In 1961, an updated forest map, based on 1959 air photos and supplementary field sampling (van Slyke 1960) was produced with stand and stock tables for the CFS-occupied portion. A similar inventory for the DND-occupied area was completed in 1967. No other inventories were made until the present one (1980), which served as a basis for later management plans (Hall 1982, Horton & Horton 1983).

Growth and yield information may be found in reports by Smithers (1954), Horton and Bedell (1960), and Stiell (1984). However, these research reports focus on individual species (white and red pine); they do not provide the general coverage needed for the present purpose.

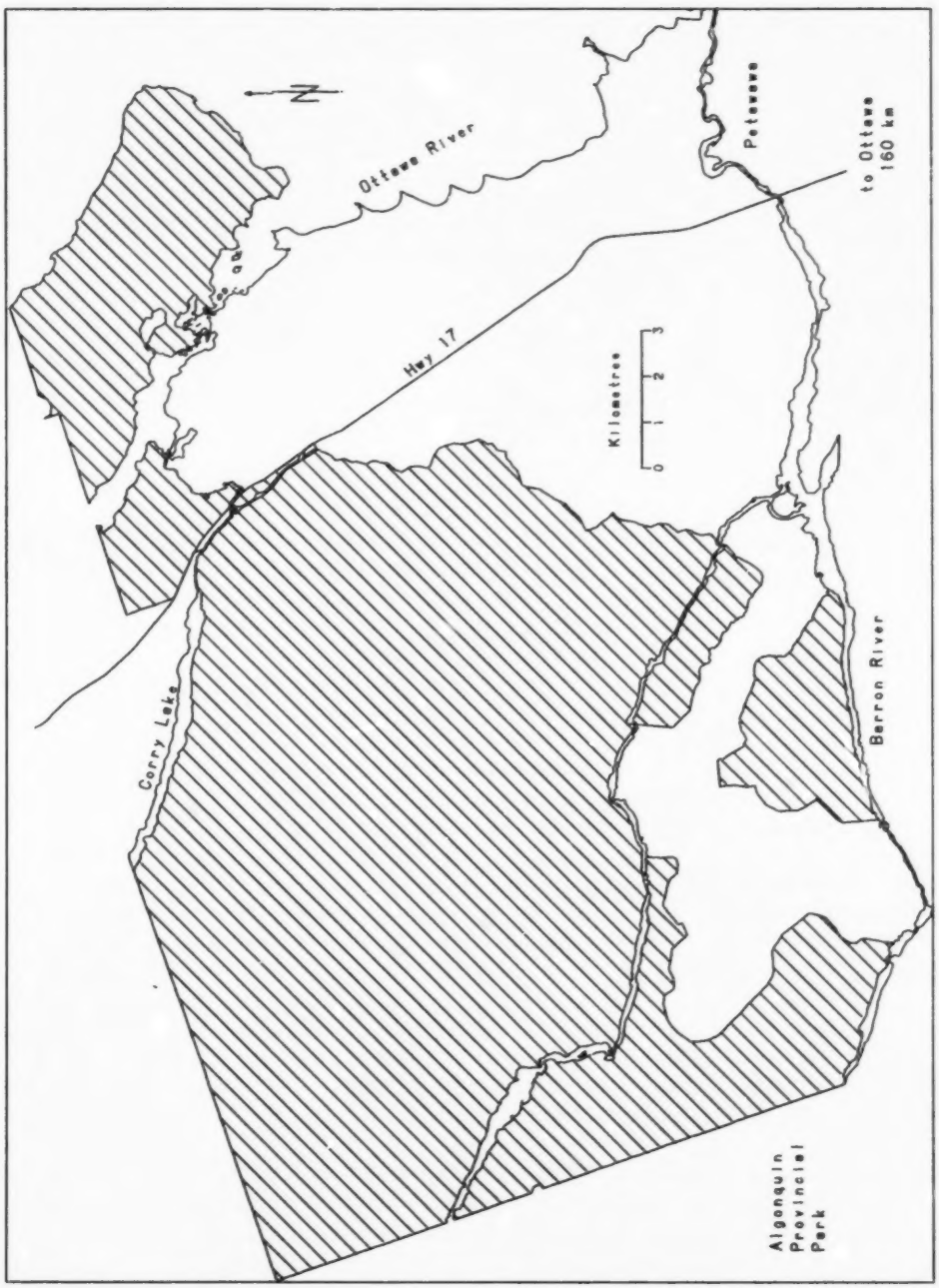


Figure 1. Federal forest lands at Petawawa — Area of 1980 inventory.

FOREST MEASUREMENTS

This section describes the two measurement phases of the study. In the first (1980) phase, a management type of inventory was completed. This inventory provided detailed area and volume data. In the second (1985) phase, the permanent sample plots (PSPs) were remeasured and growth data compiled.

Although the inventory was designed to provide estimates of wood volume and biomass, this report only presents the former. Results of the biomass compilations have been described by Alemdag and Bonnor (1985).

The 1980 Forest Inventory

The Canadian management type of inventory is characterized by a standard sequence of steps. These are described below, with modifications and detailed specifications applicable to the current inventory.

(a) Base mapping

A planimetric base map of the area was produced at a scale of 1:20 000. This map showed geographic features such as rivers, lakes, and roads, and had the Universal Transverse Mercator (UTM) 1 km grid overprinted.

(b) Air photos

Panchromatic air photos at 1:20 000 were obtained for the whole area and interpreted: the boundaries of individual stands were delineated and the characteristics of each stand (e.g., cover type, age, site) interpreted. A forest and land classification system (Appendix 2), based on the Ontario Forest Resource Inventory system, was used.

(c) Forest map

The air photo information was transferred to the base map. The resulting forest map was digitized, i.e. the boundaries and characteristics of each polygon or other feature, including the stands, were transformed into digital form, and stored in the computer. Next, the area of each polygon was calculated and area summaries tabulated. An example of the area summary is given in Appendix 3.

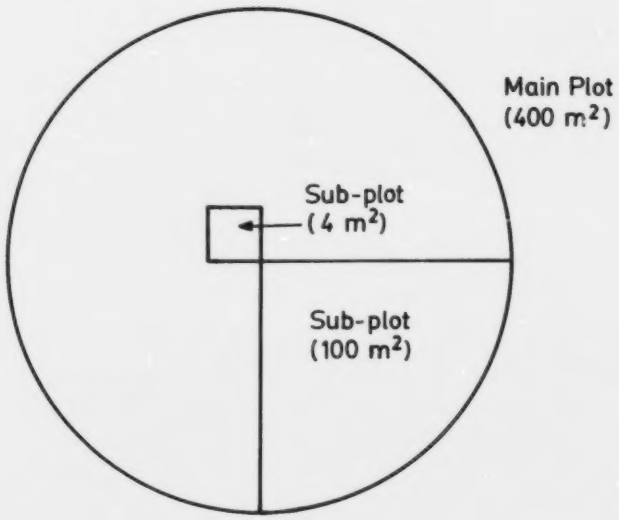
(d) Sampling

A simple random sampling design for estimating wood volume (and biomass) was chosen. The design made provision for remeasurement: one-third of the sample units were given permanent field identifiers. This design is a variation of Sampling with Partial Replacement (SPR).

Although the basic design made no provision for stratification, a decision was made to group the stands into strata and forest types for compilation purposes.

A total of 340 sample units were measured in the field work phase. Each unit consisted of three plots (Fig. 2): a 400 m^2 circular main plot, a 100 m^2 wedge shaped sub-plot, and a 4 m^2 regeneration plot. In the main plot, trees

Figure 2. Plots in sample units.



with a diameter at breast height (dbh) of at least 8.1 cm were measured: species type was determined, dbh measured, and tree height either measured or estimated. In addition, 2-3 trees were bored for age determination, and stand, soil and topographic features were noted.

In the 100 m^2 plot, saplings (0-8 cm dbh) were measured: the number of stems were tallied by species and 2 cm dbh classes. In the 4 m^2 plot, all woody stems were tallied by two height classes: 30-80 cm and 80-130 cm. The main plot data only were used in estimating wood volume, while data from all three plots were used to estimate biomass.

(e) Compilations

Merchantable tree volumes (stump height 30 cm, minimum top diameter 7 cm inside bark) were calculated from dbh using local volume equations which were derived from standard ones by Honer et al. (1983). Heights (H) were estimated from diameters (D) by the formula

$$H = 1.3 + e^{(a+b/D)}$$

where the coefficients "a" and "b" were determined by regression analysis for individual species. Relevant statistics are shown in Appendix 4.

The resulting tree volumes were aggregated by species within each plot. These were subsequently used to calculate mean volumes (m^3/ha) and sampling errors for a number of categories, including three forest types, 13 strata, and age and site classes. All volumes were calculated as gross merchantable: minimum tree size was 10.2 cm dbh, with stump height 30 cm and minimum top diameter inside bark 7.0 cm.

As a final step, the volume averages were combined with the previously obtained areas to yield total volumes for the various categories. Formulae for the calculation of means, totals, and variances are given in Appendix 5.

The 1985 Plot Remeasurements

The 113 permanent sample plots were remeasured in early 1985, five growing seasons after the initial inventory. Measurements followed the procedures outlined for the 1980 inventory, with the following additions:

a) plot disturbance, if any, was noted. Harvesting and windfall were the only types of disturbance encountered;

b) tree status (crown class) and tree condition (evidence of decay, mechanical damage) were recorded; and,

c) ingrowth trees were given permanent identification.

Also, maps of disturbances 1980-85 were prepared and area summaries (not used in this study) compiled.

In the field, the crew compared 1980 and 1985 diameter measurements and species coding, and it was able to flag and check discrepancies immediately. The data were further edited and validated in the office, followed by the calculation of individual tree volumes. The resulting data set (an example is shown in Appendix 6) was used for a variety of growth calculations; the relevant ones are described later in this report.

THE GROWTH MODEL

Growth modelling has taken many different paths. Common to all is the search for a model that describes the growth process in the real world, so that future situations can be predicted from information about the past. All such models include the basic components of tree establishment, growth, and mortality. The models differ in resolution (tree versus stand models) in the number of independent variables included (e.g. age, site quality, tree size, etc.), and in the level of growth constraints (e.g. effect of tree size and stand structure on increment) (Clutter et al. 1983, Munro 1974).

The path we took was to estimate growth and future structure of a forest from changes in diameter frequencies that result from the movement of trees from one diameter class to another. In the presence of regular shaped diameter distributions this process can be formulated mathematically (Bailey and Dell 1973, Hyink and Moser 1983, Moser 1972, 1973). However, even though plotted tree frequencies may fit a known distribution model, obvious deviations usually occur that cause discrepancies in future predictions. In the present study we have based our growth predictions on these principles but, instead of formulating mathematical models for the diameter distributions, we have chosen to describe growth as a stochastic process: the past movements of trees from one diameter class to another are used directly to predict future movements, without any recourse to probability density functions. Depending on assumptions made about the properties of the model, this growth prediction technique may be considered a modification of the stand

table projection method (Husch et al. 1972, Fairweather 1985), a Markov model (Bruner and Moser 1973, Peden 1973), or simply a growth matrix (Buongiorno and Michie 1980, Michie and Buongiorno 1984, Harrison and Michie 1985). The last approach was taken here: no a priori assumptions were made about the model.

Analytical Expression

Future diameter distributions were predicted from an initial distribution and a matrix of transition probabilities:

$$[D^{n+5}] = [D^{n}] * [P]$$

where $[D^{n+5}]$ = diameter distribution vector in year n + 5 giving frequencies (stems/ha) by 1 cm dbh classes

$[D^{n}]$ = diameter distribution vector in year n

$[P]$ = transition probability matrix (growth matrix) with elements p_{ij}

Each element p_{ij} is derived as the proportion of trees in class i that has grown to class j in the past five years. To the extent that the recent past growth is the same as the immediate future growth, p_{ij} is assumed also to represent future growth: it may be taken as the proportion of trees - or the probability of a single tree - in class i growing to class j in the next five years.

For ease of numerical analysis, growth classes were used: instead of a tree moving from diameter class i to diameter class j, it is moving j-i growth classes, where j-i = 0, 1, 2, ... The number of growth classes will, of course, depend on the width of each class, on the length of the time interval, and on the rate of tree growth.

The above explanation relates to only one of the three stand growth components, growth of survivor trees. However, it is equally appropriate for the mortality component, i.e. trees that die during the five year interval. The only change is the addition of a growth class M = mortality to the growth matrix [P]. The third growth component, ingrowth, may be handled in a similar manner by the addition of one or more diameter classes of small trees, the so-called sub-merchantable trees. Some caution must be exercised, however, in calculating proportions and in the analyses: the proportions pertain to those trees growing <u>into</u> the smaller merchantable classes, not to the number of classes moved. Also, as will be shown in an example, the width of the sub-merchantable class(es) may be different from that of the merchantable classes, resulting in proportions that are of a different magnitude.

Procedures

The basic information available from each PSP was the 1980 dbh (d_{80}) and the 1985 dbh (d_{85}) for each tree, as well as data on ingrowth trees, dead trees, and tree and plot status. For the undisturbed plots, i.e. plots not subjected to harvesting or windfall, this information was used to assign each tree to a 1 cm dbh class (based on d_{80} values) and to one of the following growth classes:

(1) ingrowth: of 1, 2, or 3 classes, i.e. into class 8, 9, or 10 cm;

(2) mortality: of trees that died between 1980 and 1985; and,

(3) survivor growth: of 0, 1, ..., 6 classes.

These data for individual trees were summarized by species, strata, and forest types to yield frequency tables, from which were calculated:

(a) diameter distribution vectors for the years 1980 and 1985 ($[D^{80}]$ and $[D^{85}]$), giving the number of trees per hectare; and,

(b) growth matrices with p_{ij} values calculated as follows:

- for ingrowth, each p_{ij} value was calculated as the number that had grown into class 8, 9, or 10 cm by 1985, expressed as a proportion of the total number of trees in the submerchantable class (0-8 cm) in 1980

- for mortality, the number of trees that died by 1985, divided by the total number of trees in the diameter class in 1980

- for survivor growth, the number of trees that grew 0, 1, ..., 6 classes between 1980 and 1985, divided by the total number of trees in the diameter class in 1980.

An example of the resulting frequency tables is given in Table 1. The data were taken from a single species within a single stratum, and includes only diameter classes up to 16 cm and growth classes up to class 3. As shown, of the 139 trees in diameter class 0-7 cm, two trees grew by one growth class (into class 8), one grew by two classes (into class 9), and 10 grew by three growth classes (into diameter class 10). The one tree in diameter class 8 died, while the tree in diameter class 9 grew by one growth class. The growth in the remaining diameter classes is presented in a similar manner. The relationship between the frequencies for 1980, 1985, and the growth classes is now apparent: for example, the 1985 frequency of 11 for diameter class 10 cm results from the one tree from diameter class 9 that grew by one class, and the 10 ingrowth trees that attained a diameter in the 10 cm range. Similarly, the frequency of 7 for diameter class 15 cm results from the two trees that did not grow out of the class, the one tree from diameter class 14 cm that grew by one class, and the four trees from diameter class 13 that grew by two classes. The 1985 frequency for the 0-7 cm class, although not listed, is assumed equal to the 1980 frequency, less growth into the larger classes.

The data from the frequency tables were then used to derive the diameter distribution vector and a series of growth matrices. An example, using the data from Table 1, is given in Table 2. The 1980 and 1985 frequencies, in trees/ha, are functions of total number of trees (given in Table 1), plot size (400 m^2), and number of plots (16 in this example). They are the diameter distribution vectors $[D^n]$ and $[D^{n+5}]$ required in equation (1). The set of growth values (Table 2), however, did not comprise the vector [P]. Rather, when multiplied by $[D^n]$, they yielded the frequency of trees that died, grew 0 classes, one class, etc. during 1980-85. To obtain [P], the proportions

Table 1. Example of frequency tables

DBH class (cm)	1980 Frequency	1980-85 Changes: Growth Classes 0	1	2	3	M	1985 Frequency
	(no. of trees)						
0-7	139		2	1	10		
8	1					1	2
9	1		1				1
10	3		1			2	11
11	4		3	1			1
12	3	2				1	5
13	12	2	4	1		5	3
14	9	1	4	1		3	5
15	9	2	4	1		2	7
16	23	3	11	3		6	8

Table 2. Example of diameter distributions and growth values

DBH class (cm)	1980 Frequency (trees/ha)	1980-85 Changes: Growth Classes 0	1	2	3	M	1985 Frequency (trees/ha)
		(proportions)					
0-7	217.2		0.01	0.01	0.07		
8	1.5					1.00	3.1
9	1.5		1.00				1.5
10	4.7		0.33			0.67	17.2
11	6.2		0.75	0.25			1.5
12	4.7	0.67				0.33	7.8
13	18.8	0.17	0.33	0.08		0.42	4.7
14	14.1	0.11	0.44	0.11		0.33	7.8
15	14.1	0.22	0.44	0.11		0.22	10.9
16	35.9	0.13	0.48	0.13		0.26	12.5
	$[D^n]$						$[D^{n+5}]$

given by growth classes must be rearranged to show the resulting 1985 diameter class:

$$[P] = \begin{bmatrix} - & 0.01 & 0.01 & 0.07 & - & - & - & - & - & - & - & - & - \\ - & - & - & - & - & - & - & - & - & - & - & - & 1.00 \\ - & - & - & 1.00 & - & - & - & - & - & - & - & - & - \\ - & - & - & - & 0.33 & - & - & - & - & - & - & - & 0.67 \\ - & - & - & - & - & 0.75 & 0.25 & - & - & - & - & - & - \\ - & - & - & - & - & 0.67 & - & - & - & - & - & - & 0.33 \\ - & - & - & - & - & - & 0.17 & 0.33 & 0.08 & - & - & - & 0.42 \\ - & - & - & - & - & - & - & 0.11 & 0.44 & 0.11 & - & - & 0.33 \\ - & - & - & - & - & - & - & - & 0.22 & 0.44 & 0.11 & - & 0.22 \\ - & - & - & - & - & - & - & - & - & 0.13 & 0.48 & 0.13 & 0.26 \end{bmatrix}$$

The rows of [P] represent 1980 diameter classes, starting with class 0-7 cm. The columns of [P] represent 1985 diameter classes (0-7 cm, 8 cm, etc.) and mortality (last column).

It can easily be verified that, when the vector $[D^n]$ of Table 2 is multiplied by the matrix [P] above, the vector $[D^{n+5}]$ of Table 2, plus mortality figures, are obtained. In a similar manner, predictions to 1990 can be made by multiplying the vector $[D^{n+5}]$ by [P], predictions can be made to 1995 by multiplying the resulting vector $[D^{n+10}]$ by [P], and so on.

The prediction of future diameter distributions can be expressed by the algorithm

$$N(k,j) = \sum_{i=j-max}^{j} N(k-1,i) * P(i,j-i+1)$$

where N(k,j) = number of trees in diameter class j in year n + 5k
(k = 1, 2, 3, 4);

i = diameter class in year n + 5(k-1);

max = upper limit of five years' diameter growth (= 6 cm); and,

P(i,j-i + 1) = probability of a tree in diameter class i in year

n + 5(k-1) entering class j in year n + 5k (j≥i).

In this expression, P(i, 1) is defined as the probability of zero growth, (P(i,2) as the probability of 1 cm growth, and so on..

The algorithm (2) formed the basis for a computer program which was used to calculate stem diameter distributions for individual species and strata in 1985, 1990, and 1995. These diameter distributions were applied to the local volume equations, and volumes (in m^3/ha) were calculated. Mortality figures were obtained directly by multiplication of frequencies with mortality probabilities.

The foregoing procedures applied to the PSP data. It was decided to augment these data with data from the temporary sample plots. This was done by combining the two data sets before compiling the 1980 diameter distribution vectors. This resulted in increased frequencies, better defined per-hectare values and, in many diameter classes, the presence of trees where previously there had been none. For these latter classes, probability values were added from the immediately preceding class.

RESULTS

This section describes the results of the two measurement phases. First, the results of the 1980 inventory are presented: areas and wood volumes of the forest are summarized by various forest and land classes. Second, the results of the 1980 and 1985 PSP measurements are presented: the growth matrix approach is used to derive volume growth estimates for the next 10 years, by various forest classes. It must be noted that while the 1980 inventory data are complete, the update to 1985 and predictions beyond 1985 relate to volume increment of the undisturbed forest only; no attempt is made to provide complete inventory data.

Forest structure 1980

Of the 21 911 ha inventoried in 1980, 18 337 ha or 84% is classified as natural forest (Table 3). The mixedwood forest type is clearly dominant, covering 59% of the forested land. Predominantly hardwood stands comprise 29% of the forest land, and softwood stands 12%.

The natural forest is grouped into strata and forest types, and summaries of areas and volumes prepared (Table 4). In the softwood type, the "pine" stratum (mostly white and red pine) predominates in both area and volume. Very few pure spruce stands exist, and they have the lowest average volume at 118 m^3/ha. Pine and aspen grow extensively on the area, mostly in mixed stands: pine is a component in strata comprising 60% of the area, while aspen is a component in strata comprising 49% of the area. Further, the stratum where pine and aspen predominate (pine-aspen-birch) has the highest average volume at 248 m^3/ha.

As indicated, average stratum volumes range from 118 to 248 m^3/ha, with an overall average of 194 m^3/ha. The mixedwood forest type has the highest average (211 m^3/ha), followed by softwood (194 m^3/ha) and hardwood (158 m^3/ha). The last was significantly affected by the fairly large area of low-volume pure red oak stands growing on relatively poor soils.

In terms of total volume, the mixedwood type predominates: over 2.2 million m^3, or 65% of the 3.4 million m^3 total volume, is in that forest type. The softwood and hardwood types contain 12% and 23%, respectively. If pure stands are isolated, i.e. those including a single species only, the total volume comes to about 1.1 million m^3, or one-third of the total; the remaining two-thirds is in mixed-species stands.

The standard error expresses the precision of volume estimates (areas are assumed to be known without error). Thus, the overall error of 3% means that, unless a 1-in-3 chance has occurred, the true volume is within 3% of the given

Table 3. Summary of areas, 1980

Forest and land type	Area (ha)
Inventoried:	
- Softwood	2 237
- Mixedwood	10 830
- Hardwood	5 270
Total natural forest	18 337
- Plantations	505
Total forest	18 842
- Non-forest land	1 582
Total land	20 424
- Water	1 487
Total inventoried	21 911
Non-inventoried:	13 192
Total Federal	35 103

Table 4. Summary by forest strata and types, 1980

Forest stratum and type	Area (ha)	Volume* (m^3/ha)	Volume* (1000 m^3)	Standard error (% of volume)	Sample plots (no.)
1. Pine	1 653	214	353	8	27
2. Spruce	584	102	59	21	8
Softwood type	2 237	184	412	8	35
3. Aspen, birch, spruce	665	120	80	13	19
4. Aspen, birch, pine	3 256	198	643	5	58
5. Pine, aspen, birch	3 226	252	814	6	48
6. Pine, oak	2 781	211	586	6	51
7. Cedar, ash, spruce	418	85	36	47	4
8. Other mixedwoods	484	162	78	15	15
Mixedwood type	10 830	207	2 237	3	195
9. Maple, birch	351	192	68	18	8
10. Oak	2 361	140	330	5	51
11. Aspen	1 796	158	284	11	29
12. Birch	692	170	117	11	8
13. Other hardwoods	70	118	8	14	3
Hardwood type	5 270	153	807	5	99
ALL	18 337	188	3 456	3	329

*Gross merchantable.

estimate. For the population, the true volume will therefore be in the 3.35-3.56 million m^3 range. The confidence level of 1-in-3 can be increased to 1-in-20 by doubling the standard error figure.

Due to the selection of sample plots with equal probability (before stratification), there was rough proportionality between stratum area and sample size (last column of Table 4). Had the natural within-stratum variability been the same in all strata, the standard errors would also have been similar. This was not the case. The standard error of stratum 7, for instance, was quite high (47%), indicating high internal variability. Allocating more sample plots to that stratum would have reduced the sampling error, but at the expense of flexibility in stratification: the equal probability selection aspect would be nullified.

A summary by major species (Table 5) also shows the dominance of white pine and aspen/poplar. Of the 34 tree species found in the forest, white pine is dominant. It has the highest volume (65 m^3/ha or 34% of total volume), the highest basal area (5 m^2/ha or 20% of total basal area), the highest stem frequency (123 stems/ha or 20% of all stems, and the second highest average dbh (23 cm compared with 24 cm for red pine). The aspen/poplar species are in second place, followed by red oak and red pine. Jointly, the pine and aspen/poplar account for 80% of the volume, 54% of the basal area, and 58% of the stems.

Analyses of diameter distributions show that the inverse J-shape is predominant. It is a distribution well known from balanced, uneven-aged, mixed forests (Meyer 1952, Moser 1976, Murphy and Farrar 1982, Zeide 1984).

Areas and volumes by development classes (Figure 3) shows that the mature forest predominates: 13 128 ha or 72% of the total area is mature forest. When multiplied by the average volume, the total is 2.6 million m^3, or 75% of the overall total. Two additional classes are not plotted: regeneration comprises only a very small area, with no merchantable volume, and no area is classified as overmature.

Table 5. Summary by major species, 1980

Species	Volume* (m^3/ha)	(%)	Basal area (m^2/ha)	(%)	Frequency (no/ha)	(%)	DBH (cm) Average	Range
White pine	65	34	5	21	123	21	23	8-79
Aspen/poplar	42	22	3	13	86	14	22	8-64
Red pine	22	12	2	8	44	7	24	8-61
Red oak	22	12	3	13	93	16	21	8-61
White birch	12	6	2	8	56	9	20	8-48
Maple	9	5	1	4	86	14	14	8-57
Spruce	9	5	1	4	45	7	18	8-56
Other	7	4	7	29	67	12	21	8-65
All	188	100	24	100	600	100	19	8-79

*Gross merchantable.

Site quality is derived from Plonski's yield tables (Plonski 1981). Site index classes are based on 5-m intervals (base age 50 years). Class 1 represents the 26+ m range, Class 2 the 21-25 m range, and so on. Figure 4 shows that Class 3 dominates: 68% of the area (12 558 ha) and 71% of the volume (2.5 million m^3) belong to this class. The best site (Class 1) is not plotted because the area is very small and the volume negligible. As expected, the average volume decreases with decreasing site index.

The last 1980 data summary is a stand and stock table by major species and by three size classes (Table 6). The figures are self-explanatory and do not hold any surprises. However, the average tree sizes calculated from them range from 0.07 m^3 for small maples to 2.60 m^3 for large white pines. This difference remains at higher summary levels: the average coniferous tree has a volume of 102/256 = 0.40 m^3, while the average deciduous tree only attains a volume of 86/344 = 0.25 m^3. If all species are combined, the small class yields 50/426 = 0.12 m^3, the large one 19/7 = 2.71 m^3.

Growth and Yield

As previously noted, the growth and yield predictions are derived for the undisturbed natural forest using the growth matrix model.

Table 7 summarizes, for individual strata, the 1985 volumes, the predicted volumes in 1990 and 1995, and the periodic annual increments between these dates. It was derived from stock tables by individual species and strata, an example of which is given in Appendix 7. Volume and growth figures (Table 7) vary considerably: the highest increments were found in the strata with pine dominance (strata 1 and 5), while the stratum 'Other hardwoods' displayed low, even negative, growth indicating reduced vigour and/or mortality. However, the impact of this negative growth was negligible: the stratum comprised less than 1% of the total volume. Overall, the average volume increased from 188 to 253 m^3/ha, an increase of 65 m^3/ha or 35% for the 15-year period. For the three five-year periods, the average annual volume increment remains almost constant at 4.3 m^3/ha/yr. In percentage terms the increment decreases from 2.2% in the first period to 1.8% in the last period.

Volume changes by forest types are illustrated in Figure 5, which is derived from data in Appendix 8. In 1985, the softwood, mixedwood, and hardwood types account for 12%, 64%, and 24% of the volume, respectively. During the following 10-year period, the softwood type grew slightly faster than the mixedwood type, which again grew faster than the hardwood type (increments are 46, 44, and 37 m^3/ha, respectively). However, on a percentage basis, the increments are similar, at about 21%. As shown, the forest type areas were assumed to remain the same during the 10-year period.

Volumes and stem frequencies are shown in Tables 8 and 9 by major species groups and size classes. In terms of volume (Table 8), white pine is expected to increase from 74 to 94 m^3/ha by 1995, corresponding to an annual rate of 2.0 m^3/ha·yr, thereby increasing its dominant position in the forest. As expected, the increase occurred in the larger two size classes. This dominance of white pine does not extend to stem frequency (Table 9). Most species, including white pine, decreased in frequency, especially in the small size class. The conclusion is that there will be fewer but larger trees in the forest in 1995: average tree size will go from 0.34 to 0.42 m^3, an increase

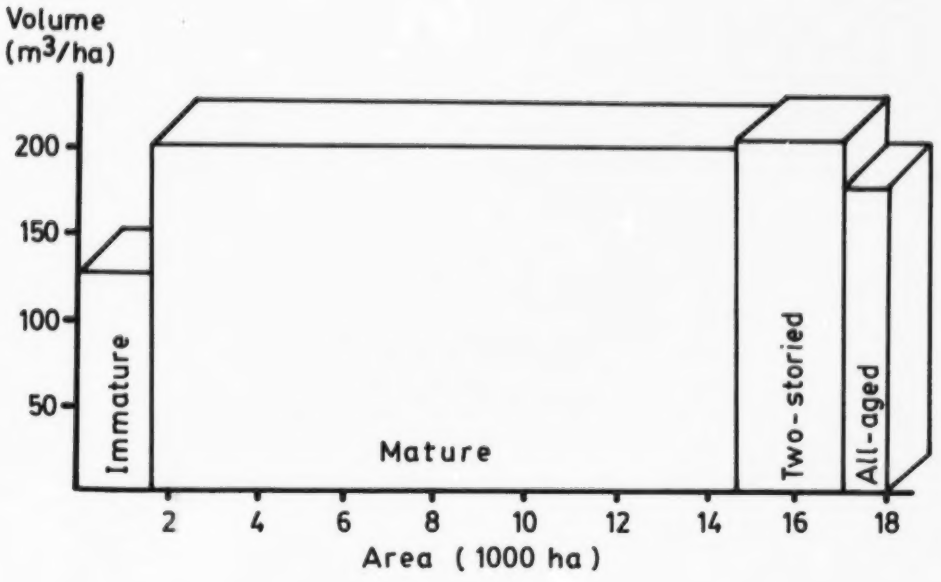


Figure 3. Areas and volumes by development classes.

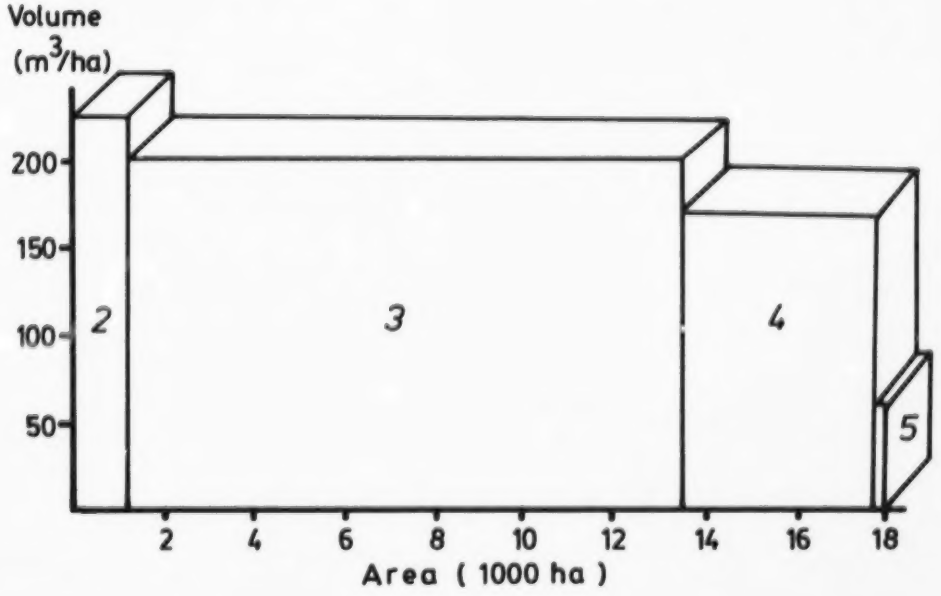


Figure 4. Areas and volumes of site index classes.

Table 6. Stand and stock table, 1980

Species	dbh class (cm)							
	10-24		25-49		50+		All	
	Volume* (m^3/ha)	Frequency (trees/ha)	Volume* (m^3/ha)	Frequency (trees/ha)	Volume* (m^3/ha)	Frequency (trees/ha)	Volume* (m^3/ha)	Frequency (trees/ha)
White pine	9	71	43	47	13	5	65	123
Red pine	3	23	17	20	2	1	22	44
Spruce	4	36	4	9	1	-	9	45
Other coniferous	3	37	3	7	-	-	6	44
All coniferous	19	167	67	83	16	6	102	256
Aspen	7	44	32	41	3	1	42	86
Oak	10	69	11	24	-	-	22	93
White birch	7	44	6	11	-	-	12	55
Maple	6	81	3	6	-	-	9	87
Other deciduous	1	21	-	2	-	-	1	23
All deciduous	31	259	52	84	3	1	86	344
All species	50	426	119	167	19	7	188	600

*Gross merchantable.

Table 7. Volumes by strata

Stratum	Volume (m^3/ha)				Annual Volume Increment (m^3/ha·yr)			Annual Volume Increment (%)		
	1980	1985	1990	1995	1980-85	1985-90	1990-95	1980-85	1985-90	1990-95
Pine	214	241	262	284	5.4	4.2	4.3	2.3	1.7	1.6
Spruce	102	126	151	180	4.8	5.1	5.7	4.1	3.6	3.5
Aspen-birch-spruce	120	134	146	159	2.7	2.5	2.6	2.2	1.7	1.7
Aspen-birch-pine	198	216	234	254	3.7	3.7	3.9	1.7	1.6	1.6
Pine-aspen-birch	252	282	310	340	5.9	5.7	6.0	2.2	1.9	1.8
Pine-oak	211	233	255	278	4.4	4.4	4.7	5.9	1.8	1.7
Cedar-ash-spruce	85	90	95	100	1.0	1.0	1.0	1.1	1.1	1.0
Other mixedwoods	162	183	205	228	4.3	4.4	4.5	2.4	2.2	2.1
Maple-birch	192	213	236	256	4.0	4.6	3.9	2.1	2.1	1.6
Oak	140	154	168	186	2.8	2.9	3.5	1.9	1.8	2.0
Aspen	158	184	211	232	5.3	5.3	4.3	3.0	2.7	1.9
Birch	170	186	204	223	3.2	3.5	3.9	1.8	1.8	1.8
Other hardwoods	118	119	111	114	0.1	-1.6	0.6	0.2	-1.4	0.5
All	188	210	231	253	4.3	4.2	4.3	2.2	1.9	1.8

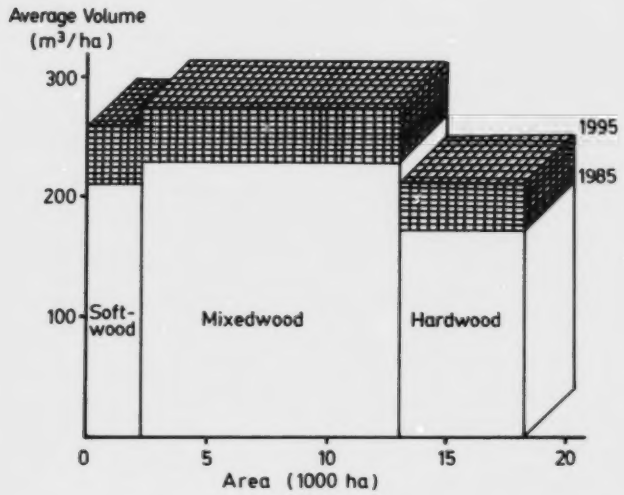
Table 8. Stock Table, 1985-95

Species	dbh classes (cm)											
	10-24			25-49			50+			All		
	1985	1995	Change	1985	1995	Change	1985	1995	Change	1985	1995	Change
	Volume (m^3/ha)											
White pine	10	10	0	47	56	9	17	28	11	74	94	20
Red pine	3	3	0	18	21	3	3	3	0	24	27	3
Spruce	4	4	0	5	7	2	1	1	0	10	12	2
Other coniferous	4	5	1	4	4	0	0	1	1	8	10	2
All coniferous	21	22	1	74	88	14	21	33	12	116	143	27
Aspen/poplar	7	7	0	37	42	5	3	6	3	47	55	8
Oak	9	7	-2	13	17	4	-	1	1	22	25	3
White birch	6	6	0	7	9	2	-	-	-	13	15	2
Maple	7	9	2	3	4	1	1	0	-1	11	13	2
Other deciduous	1	0	-1	0	1	1	0	1	1	1	2	1
All deciduous	30	29	-1	60	73	13	4	8	4	94	110	16
All species	51	51	0	134	161	27	25	41	16	210	253	43

Table 9. Stand table, 1985-95

Species	dbh classes (cm) 10-24			25-49			50+			All		
	1985	1995	Change	1985	1995	Change	1985	1995	Change	1985	1995	Change
	Frequency (no./ha).											
White Pine	74	60	-14	50	59	9	6	10	4	130	129	-1
Red Pine	21	16	-5	21	23	2	1	1	0	43	40	-3
Spruce	37	36	-1	10	12	2	0	1	1	47	49	2
Other coniferous	42	48	6	8	11	3	1	0	-1	51	58	7
All coniferous	174	160	-14	89	105	16	8	12	4	271	276	5
Aspen/poplar	46	37	-9	45	47	2	1	2	1	92	86	-6
Oak	58	39	-19	28	35	7	0	0	0	86	74	-12
White birch	39	32	-7	14	18	4	0	0	0	53	50	-3
Maple	90	88	-2	6	8	2	1	1	0	97	97	-0
Other deciduous	23	22	-1	2	4	2	0	0	0	25	26	1
All deciduous	256	218	-38	95	112	17	2	3	1	353	333	-20
All species	430	378	-52	184	217	33	10	15	5	624	609	-15

Figure 5. Volume predictions and areas by forest types.



of 24%. The four dominant species (white pine, red pine, aspen/poplar, and oak) will all increase by over 20%. A few species groups ("Other coniferous", mostly balsam fir, and "Spruce") do show increases in frequency. This is likely due to their recovery from spruce budworm attacks.

The above information indicates that the forest may not be in a balanced state but maturing, perhaps even becoming overmature, with the spruce-balsam fir component being re-established. That is confirmed by a separate calculation of individual growth components (Table 10). It shows that the number of trees dying exceeds the number of ingrowth trees. Also, mortality by volume was quite high, comprising 27% of gross growth or almost 1% of gross merchantable volume. An assessment of mortality by species showed that red oak had the highest mortality rate. For example, although it comprised only 12% of total volume, it accounted for 26% of total mortality. White pine, on the other hand, has a low mortality rate and the comparable figures are 35% and 22%.

DISCUSSION

Methodology

The basic inventory method employed in this study has been used operationally for many years and is well documented. It provides static inventory data in an effective manner, at a reasonable cost. Two modifications were made to the basic method, both relating to the field sampling units. The establishment of sub-plots and measurement of regeneration and sub-merchantable trees, while extending the time spent on each sampling unit, does not cause any significant problems. Similarly, the decision to include both temporary and permanent sampling units in the inventory does not cause any significant problems.

Table 10. Stand growth components, 1980-85

Growth component	Volume (m^3/ha·yr)	Frequency (stems/ha·yr)
Gross growth	5.9	12.8
Mortality	-1.6	-8.0
Net growth	4.3	4.8
Survivor growth	4.3	-
Ingrowth	0.02	4.8

Furthermore, although no time records were kept, the time required to establish and measure a permanent unit does not appear to differ significantly from that of a temporary unit: on the average, one person-day per unit is required.

The results presented here, and those presented in a (unpublished) report by Bonnor and Magnussen, are compiled from the same basic inventory data. The slight differences in the figures are due to the use of stratified random sampling in the other report, simple random sampling (SRS) here. Simple random sampling is used here to simplify stem diameter projection procedures.

The 1985 survey, in which the permanent sample plots were remeasured, provides an opportunity to check the accuracy of the measurements. While the dbh measurements are of acceptable accuracy, the tree heights are not; numerous cases of negative or excessive height growth are encountered. To eliminate any effect of these errors, the 1980 data were used to derive height-diameter relationships which, in turn, were used to produce the local volume equations. However, the use of such local equations in growth predictions assumes that the height-diameter relationship is constant over time. This assumption may not be true, but the effect on the present results is expected to be insignificant.

The core of the growth model is the probability matrix. The values of this matrix relate to survivor growth, mortality, and ingrowth. Probability values of other events, e.g. harvesting, are deliberately excluded and only events relevant to the natural, undisturbed forest are considered.

The probability matrix is derived from past growth measurements but used to predict future growth. Thus, probability values in the matrix are assumed to remain fairly constant. The extent to which this assumption is correct will determine the accuracy of the predictions. Obviously, the longer the prediction period, the greater the chance for error.

While the existence of data for only one measurement period precluded any assessment of accuracy, some potential sources of error must be mentioned. One was the lack of any growth restraints apart from those inherent in the calculated growth and mortality probabilities. This led to a nearly constant growth rate which - over long prediction periods - may be incorrect due to increased competition. While some models were modified to take into account such competition (Adams and Ek 1974, Ek 1974, Holdaway 1984, Hyink and Moser 1983, Moser 1972), the generally low stocking level and modest growth rates of

this forest make growth restrictions due to competition unlikely in the short term (Stiell 1984). Other potential sources of error - or opportunities to improve the accuracy of the model - are variations in growth rates with site quality, tolerance class (Cassell and Moser 1974), and crown class (Roberts and Huska 1985). Also, ingrowth may vary with basal area and tree frequency (Buongiorno and Michie 1980).

Bias may have been introduced by using 1-cm classes as the unit for diameters and diameter increments. With an average 5-year diameter growth of only 1 cm, any deviation from a rectangular distribution within a diameter class would have led to over- or under-estimation of growth. The problem is not solved by using smaller units of the diameter increments which would have only led to fewer observations in each diameter class and thus to less precise estimation of growth probabilities. Furthermore, with smaller units of growth, the associated measurement errors in dbh must be recognized. In the present study, this source of bias can be ignored in all major tree species and cover types, but may be significant in minor tree species. This problem is addressed by Harrison and Michie (1985), who also discuss the problem of making growth predictions for intervals different from the remeasurement period.

The results

Most forest land in Canada is managed for wood production, e.g. to produce sawlogs and pulpwood. This is not the case for the Petawawa forest where there are no such management objectives against which the adequacy of the resources can be weighed. Hence, this analysis will focus on the structure of, and changes in, the forest, how the inventory data compare with data from other sources, and what the implications might be for forest management.

The inventory results contain two surprises. One relates to site quality and accompanying growth rates, the other to species composition.

Site quality of the Petawawa forest is relatively high. As defined by the site index (SI) classes, there is no unproductive forest land (SI = 0-5 m). At the other end of the scale, some 1200 ha exceed SI = 20 m, high by Canadian standards. These figures are supported by the high average volume (210 m^3/ha in 1985) and growth rate (over 4 m^3/ha·yr).

A general comparison between these results and growth and yield figures from surrounding regions reveals considerably higher levels of both growing stock and increment in the federal forest. Inventory summaries for Renfrew County, for example, show 40-100% lower volume and growth figures (Anon. 1984) than in comparable cover types of the Petawawa forest. The observed differences increase with increasing conifer, especially pine, content. The heavier exploitation of conifers in the Pembroke District forests explains in part the substantial divergence. Another factor is the use of Plonski's yield tables (Plonski 1981), which are used to estimate volume and growth in the Pembroke District. For comparable site class and stocking, these tables predict volume figures that are 20-100% lower than observed here. Thirdly, errors in the volume estimates could be a significant factor.

The 1929 timber survey in the Algonquin area offers an interesting comparison (Anon. 1937). It shows growth figures for conifers and deciduous

species comparable to those presented here, but also much less growing stock per hectare due to preceding exploitations. Similarly, the current average volumes are considerably higher than those obtained in a previous cruise (Van Slyke 1960).

The above differences may to some extent be explained by the emergence of white pine as the most important species. This has come about due to a lack of felling, the superior growth rate of white pine (4.4 m^3/ha·yr), and the decline of balsam fir and white spruce due to spruce budworm attacks. For instance, the volume of balsam fir decreased from 8.3% to 1.2% of the total between 1960 and 1980. In the same period, white pine volume increased from 18% to 34%. The predictions to 1995 show a further increase to 37%.

Growth and yield data for white pine obtained from permanent sample plots on the "Headquarters Silvicultural Area"* and "PNFI Natural Areas"* compare favourably with the present inventory data and growth estimates. Studies by Stiell (1984) and Smithers (1954) in unmanaged stands of the Petawawa forest covering a wide range of sites have found current annual increment in white pine ranging from 4.2-7.6 m^3 per hectare per year. Other studies in the region indicate an expected average annual increment of 4.5 m^3 per hectare in fully stocked white pine stands held in a rotation of 100 years (Horton and Bedell 1960).

The aspen-poplar species are second in volume, at 22%. Compared with white pine, they are not as widespread and individual trees are somewhat smaller. Red pine and red oak each comprise 11% of total volume but, where red pines are large and occur in few locations, the oaks are small and occur over extensive areas.

Were the forest to be managed for wood production, relatively high returns would result: despite a relatively high merchantability limit (10.2 cm dbh), the net growth rate is good (4.3 m^3/ha·yr). This return could be increased by salvaging most, if not all, of the mortality (1.6 m^3/ha·yr). The predominance of white pine is shown by its high volume and growth rate, low mortality, large average size, and widespread occurrence. Any management of the forest would do well to focus on this species. In addition to these silvicultural considerations, the high market value of white pine would be of significance in any management for economic gain.

CONCLUSIONS

This study shows that a Canadian type of forest management inventory can be modified successfully to produce growth data, and that such growth data can be used successfully to predict future growth by diameter classes. The procedures involved are not new but they have been used infrequently in Canada and, to our knowledge, not documented. This study provides such documentation. It forms the basis for additional studies designed to meet the needs of intensive forest management in the Canadian context.

The modifications to the basic inventory are simple yet sufficient to provide a basis for the subsequent acquisition of growth data. Remeasurement

*Data on file at Petawawa National Forestry Institute.

of the permanent sample plots also provides an opportunity to update the inventory.

The growth probability matrix model used here is well suited to the natural type of forest at Petawawa: mixed species, largely unevenaged, with little or no forest management. This is supported by the predicted values, which appear to be reasonable. As new data from additional measurements become available, errors can be identified and projections refined. With improvements, the growth probability matrices could be used to make predictions for similar forests in other locations with acceptable results.

The model used here is also well suited to the intended application, i.e. short term, detailed predictions suitable for intensive forest management and planning of small areas. In the longer term, the process becomes less accurate, uncertainties due to disturbances (harvesting, fire) intervene, and the detail of the predictions becomes irrelevant if not misleading.

Forest growth modelling is - or should be - a routine step in the sequence of forest management activities. Without growth models, we would be hard pressed to make intelligent management decisions. The forest manager, in choosing appropriate growth models, must be concerned with his ability to provide answers to forest management questions, and to do so reliably. The current model may need modifications or await verification from additional measurements, but it provides a sound basis for further developments, as well as an opportunity to strengthen our understanding of the way forests develop.

LITERATURE CITED

Adams, D.M.; Ek, A.R. 1974. Optimizing the management of uneven-aged forest stands. Can. J. Forest Res. 4: 274-287.

Alemdag, I.S.; Bonnor, G.M. 1985. Biomass inventory of federal forest lands at Petawawa: a case study. For. Chron. 61: 81-86.

Anon. 1937. Summary of stand and increment (rate of growth survey data, 1929), Algonquin Park, Ontario. Can. Dept. Mines Resour., For. Serv., Res. Notes 48.

Bailey, R.I.; Dell, T.R. 1973. Quantifying diameter distributions with the Weibull function. Forest Sci. 19: 97-104.

Bickerstaff, A. 1948. Management Plan - Petawawa Forest Experiment Station. Petawawa Rep. No. 60 (unpubl.).

Bonnor, G.M.; Magnussen, S. 1986. Forest Inventories in Canada: A Framework for Change. Unpubl.

Boughner, C.C. 1964. The distribution of growing degree days in Canada. Canadian Meteorological Memoirs. No. 17. Meteorological Branch, Dept. Transport. Toronto, Ontario.

Bruner, H.D.; Moser, J.W., Jr., 1973. A Markov chain approach to the prediction of diameter distributions in uneven-aged forest stands. Can. J. Forest Res. 3: 409-417.

Buongiorno, J.; Michie, B.R. 1980. A matrix model of unevenaged forest management. Forest Sci. 26: 609-625.

Cassel, R.F.; Moser, J.W. 1974. A programmed Markov model for predicting diameter distribution and species composition in unevenaged forests. Purdue Univ., Agr. Exp. Sta., W. Lafayette, Ind. Res. Bull. 915.

Clutter, F.L.; Fortson, J.C.; Pienaar, L.V.; Brister, G.H.; Bailey, R.L. 1983. Timber Management: A Quantitative Approach. F. Wiley and Sons, N.Y.

Fairweather, S.E. 1985. Stand table projection on the microcomputer. North. J. Appl. For. 2: 55-56.

Hall, W.W. 1982. Forest management and operation plan for Department of National Defense lands, Canadian Forces Base Petawawa 1982-1992. Unpubl.

Harrison, T.P.; Michie, B.R. 1985. A generalized approach to the use of matrix growth models. Forest Sci. 31: 850-856.

Holdaway, M.R. 1984. Modeling the effect of competition on tree diameter growth as applied in stems. USDA Forest Service, Gen. Techn. Rep. NC-94. p. 1-9.

Honer, T.G.; Ker, M.E.; Alemdag, I.S. 1983. Metric timber tables for the commercial tree species of central and eastern Canada. Dept. Environ. Can., Can. For. Serv., Maritimes Forest Res. Cen., Inf. Rep. M-X-140.

Horton, K.W.; Horton, B.F. 1983. Management plan for the Petawawa National Forestry Institute managed forest area. Unpubl.

Horton, K.W.; Bedell, G.H.D. 1960. White and Red Pine: Ecology, Silviculture and Management. Can. Dept. Northern Aff. and Nat. Res., For. Branch Bull. 124.

Husch, B.; Miller C.I.; Beers, T.W. 1972. Forest Mensuration. 2nd ed., Ronald Press.

Hyink, D.M.; Moser, J.W. 1983. A generalized framework for projecting forest yield and stand structure using diameter distributions. Forest Sci. 29: 85-95.

Meyer, H.A. 1952. Structure, growth and drain in balanced uneven-aged forests. J. For. 50: 85-92.

Michie, B.R.; Buongiorno, J. 1984. Estimation of a matrix model of forest growth from re-measured permanent plots. For. Ecol. & Mgt. 8: 127-135.

Moser, J.W., Jr. 1976. Specification of density for the inverse J-shaped diameter distribution. Forest Sci. 22: 177-180.

Moser, J.W., Jr. 1973. A system of equations for the components of forest growth. Purdue University Agr. Exp. Sta. Journal Paper 5236.

Moser, J.W., Jr. 1972. Dynamics of an uneven-aged forest stand. Forest Sci. 18: 185-191.

Munro, D.D. 1974. Forest growth models - a prognosis. Pages 7-21 in Fries, J. ed. Growth Models for Tree and Stand Simulation. Res. Notes No. 34, Dept. of Forest Yield Research. Stockholm.

Murphy, P.A.; Farrar, R.M. 1982. Calculation of theoretical uneven-aged stand structures with the exponential distribution. Forest Sci. 28: 105-109.

Peden, L.M.; Williams, J.S.; Frayer, W.E. 1973. A Markov model for stand projection. Forest Sci. 19: 303-314.

Plonski, W.L. 1974. Normal Yield Tables (Metric). Ontario Ministry of Natural Resources.

Roberts, M.R.; Hruska, H.J. 1985. Predicting diameter distributions: a test of the stationary Markov model. Can. J. Forest Res. 16: 130-135.

Rowe, J.S. 1972. Forest regions of Canada. Environ. Can., Can. For. Serv., Ottawa, Pub. No. 1300.

Smithers, L.A. 1954. Thinning in red and white pine stands at Petawawa Forest Experiment Station. Silvicultural Research Note No. 105, Dept. Northern Aff. Nat. Res., For. Branch, For. Res. Div.

Stiell, W.M. 1984. Improvement cut accelerates white pine sawlog growth. For. Chron. 59: 3-9.

van Slyke, A.K. 1960. Stand Description of Area "B" Petawawa Military Reserve (Proj. P-248). Canada Dept. Northern Aff. Nat. Res., For. Branch, For. Res. Div. Unpubl.

Zeide, B. 1984. Exponential diameter distribution: Interpretation of coefficients. Forest Sci. 30: 907-912.

APPENDICES

Appendix 1

SPECIES NAMES AND CODES

Common name	Latin name	Code No.
Pine	Pinus L.	00
Eastern white pine	Pinus strobus L.	20
Red pine	Pinus resinosa Ait.	30
Jack pine	Pinus banksiana Lamb.	40
Spruce	Picea A. Dietr.	100
White spruce	Picea glauca (Moench) Voss	130
Black spruce	Picea mariana (Mill.) B.S.P.	110
Balsam fir	Abies balsamea (L.) Mill.	210
Larch	Larix laricina (Du Roi) K. Koch	310
Eastern white cedar	Thuja occidentalis L.	410
Hemlock	Tsuga canadensis (L.) Carr.	510
Aspen/poplar	Populus L.	600
Birch	Betula L.	700
White birch	Betula papyrifera Marsh.	710
Yellow birch	Betula alleghaniensis Britton	720
Maple	Acer L.	800
Hard maple	Acer saccharum Marsh.	810
Red maple	Acer rubrum L.	820
Black ash	Fraxinus nigra Marsh.	912
Basswood	Tilia americana L.	920
Beech	Fagus grandifolia Ehrh.	930
Pin cherry	Prunus pensylvanica L.F.	944
White elm	Ulmus americana L.	951
Ironwood	Ostrya virginiana (Mill.) K. Koch	970
Red oak	Quercus rubra L.	983
White oak	Quercus alba L.	981

Appendix 2

Forest and Land Classification System and Classes

Forest and Land Classification System

Total inventory area

- Jurisdiction
  - CFS occupied
  - DND occupied
- Land Class
  - Water
  - Land
    - Forest class
      - Non-forest
      - Plantations
      - Natural forest
        - Species composition
        - Stratum
        - Forest type
        - Site index
        - Stand height
        - Crown closure
        - Development

Natural Forest Classes

1. Species composition

   - Up to four species, each comprising at least 25% of the stand crown closure.

2. Stratum

   - Combination of species composition classes:

Stratum No.	Stratum name
1	Pine
2	Spruce
3	Aspen-birch-spruce
4	Aspen-birch-pine
5	Pine-aspen-birch
6	Pine-oak
7	Cedar-ash-spruce
8	Other mixedwoods
9	Maple-birch
10	Oak
11	Aspen
12	Birch
13	Other hardwoods

Appendix 2 (Cont'd)

3. Forest type

- Combination of species composition classes:

Code	Forest type Symbol	Name	Coniferous species (% of total crown closure)	Strata included
1	S	Softwoods	76+	1, 2
2	M	Mixedwoods	26-75	3-8
3	H	Hardwoods	0-25	9-13

4. Site index (base age 50 years)

Code	Class (m)
1	26+
2	21-25
3	16-20
4	11-15
5	6-10
6	0-5 (unproductive)

5. Stand height

Code	Class (m)
1	0-5
2	6-10
3	11-15
4	16-20
5	21-25
6	26-30
7	31+

6. Crown closure

Code	Class (%)
1	0-25
2	26-50
3	51-75
4	76-100

7. Development (age) classes

Code	Symbol	Class
1	R	Regeneration
2	I	Immature
3	M	Mature
4	O	Overmature
5	T	Two-storied
6	A	All-aged

8. Non-forest classes

Symbol	Class
U-1	Upland-herbs
U-2	Upland-shrubs
M-1	Lowland-emergent vegetation
M-2	Lowland-sedges and grasses
M-3	Lowland-shrubs, herbs and sedges
FL	Flooded land
UCL	Unclassified

Appendix 3

Example of Area Summary of Stands

UTM Location reference	Jurisdiction	Stand number	Height class	Species composition	Crown closure class	Development class	Site index class	Forest type	Area (ha)	Stratum
18 305 5087	2	746	3	0 0 0 912	3	3	4	3	4	13
18 306 5087	2	747	5	0 10 600 710	4	3	3	2	16	5
18 306 5087	2	748	4	0 10 600 100	1	3	4	2	17	5
18 307 5087	2	749	5	0 0 10 600	4	3	3	2	27	5
18 307 5087	2	750	4	0 0 0 10	4	3	3	1	7	1
38 308 5087	2	751	5	0 0 0 10	4	3	3	1	31	1
18 308 5087	2	752	5	0 0 10 600	4	5	3	2	35	5
18 309 5087	2	753	5	0 0 30 20	4	3	2	1	8	1
18 309 5087	2	754	5	0 0 10 600	2	5	3	2	16	5

Appendix 4

Tree Volume Equation Statistics

1. Standard (two-variable) equations

Models: $V_t = c_1 D^2 / (a_1 + b_1/H)$

where V_t = gross total volume (m^3)
D = stem diameter at breast height (cm)
H = total tree height (m)

a_1, b_1, c_1 = regression coefficients

$$V_m = V_t (a_2 + b_2 X + c_2 X^3)$$

where V_m = gross merchantable volume (m^3)

$$X = \left(\frac{d}{D}\right)^2 \left(1 + \frac{h}{H}\right)$$

with d = top diameter inside bark = 7 cm
h = stump height = 30 cm

a_2, b_2, c_2 = regression coefficients

Code	Species	coefficients					
		a_1	b_1	c_1	a_2	b_2	c_2
20	White pine	0.691	110.8558	.0043188	.9735	-.2386	-0.7620
30	Red pine	0.710	108.3869	.0043313	.9672	-.0398	-1.0805
40	Jack pine	0.897	106.2228	.0043313	.9635	-.1520	-0.8298
110	Black spruce	1.588	104.6203	.0043264	.9526	-.1042	-0.8438
130	White spruce	1.440	104.3026	.0043218	.9611	-.2494	-0.7007
210	Balsam fir	2.139	91.9277	.0043310	.9352	-.0400	-0.8367
300	Larch	1.588	101.6203	.0043310	.9352	-.0400	-0.8367
310	Tamarack	1.588	101.6203	.0043264	.9645	-.1638	-0.8164
410	Eastern white cedar	4.167	74.6455	.0043298	.9645	-.1638	-0.8164
510	Eastern hemlock	1.112	106.7105	.0043298	.9645	-.1638	-0.8164
600	Poplar spp.	-.312	133.1062	.0043405	.9354	-.0968	-1.1874
610	Trembling aspen	-.312	133.1062	.0043405	.9354	-.0968	-1.1874
620	Largetooth aspen	-.312	133.1062	.0043405	.9354	-.0968	-1.1874
630	Balsam poplar	-.312	133.1062	.0043405	.9354	-.0968	-1.1874
710	White birch	2.222	91.5619	.0043218	.9087	-.3096	-0.2690
720	Yellow birch	1.449	105.0750	.0043119	.8778	-.2456	-0.5382
800	Maple spp.	1.046	117.0432	.0043336	.9057	-.0717	-0.8590
810	Sugar maple	1.046	117.0432	.0043336	.9057	-.0717	-0.8590
820	Red maple	1.046	117.0432	.0043336	.9057	-.0717	-0.8590
840	Silver maple	1.046	117.0432	.0043336	.9057	-.0717	-0.8590
910	Ash spp.	0.634	134.2644	.0043336	.9057	-.0717	-0.8590
911	White ash	0.634	134.2644	.0043336	.9057	-.0717	-0.8590
912	Black ash	0.634	134.2644	.0043336	.9057	-.0717	-0.8590
914	Northern red ash	0.634	134.2644	.0043336	.9047	-.0717	-0.8590
925	Green ash	0.634	134.2644	.0043336	.9057	-.0717	-0.8590
920	Basswood	0.948	122.3772	.0043336	.9057	-.0717	-0.8590
930	Beech	0.959	102.0470	.0043336	.9057	-.0717	-0.8590
944	Pin cherry	1.877	101.3765	.0043336	.9057	-.0717	-0.8590
951	White elm	0.634	134.2644	.0043336	.9057	-.0717	-0.8590
970	Ironwood	1.877	101.3765	.0043336	.9057	-.0717	-0.8590
981	White oak	1.512	102.5652	.0043336	.9057	-.0717	-0.8590
983	Red oak	1.512	102.5652	.0043336	.9057	-.0717	-0.8590
986	Bur oak	1.512	102.5652	.0043336	.9057	-.0717	-0.8590
000	Others	1.000	100.0000	.0043336	.9500	-.1600	-0.8500

2. Height - diameter equations (for converting standard equations to local ones).

Model: $H = 1.3 + e^{a+b/D}$

where H = tree height (m)
D = stem diameter at breast height (cm)
a, b = regression coefficients

Stratum	Species	Coefficients a	b	SEE[1]	N[2]	Max height (m)
1. Pine	White pine	3.564	-16.370	0.28	241	30.0
	Red pine	3.445	-13.950	0.34	168	27.5
	Jack pine	3.227	-11.773	0.34	89	21.6
	White spruce	3.425	-15.085	0.40	41	20.0
	Aspen/poplar	3.271	-8.998	0.58	20	27.0
	White birch	3.432	-16.512	0.66	18	17.0
	Maple spp.	3.238	-10.989	0.29	39	18.5
	Oak	2.904	-9.768	0.60	26	17.9
2. Spruce	Black spruce	3.358	-11.978	0.34	55	20.7
	White spruce	3.207	-12.335	0.62	24	23.4
	Balsam fir	3.125	-9.713	0.55	32	20.0
	Larch	2.991	-7.182	0.35	58	17.0
	E. white cedar	3.004	-13.707	0.74	31	14.6
3. Aspen, birch, spruce	White pine	3.681	-22.217	0.55	17	24.5
	White spruce	3.332	-13.162	0.51	46	26.0
	Balsam fir	3.001	-10.280	0.37	52	18.7
	Aspen/poplar	3.259	-8.550	0.35	134	26.0
	White birch	3.427	-14.952	0.38	67	19.2
	Maple spp.	3.001	-8.014	0.52	66	19.0
4. Aspen, birch, pine	White pine	3.184	-11.295	0.29	291	29.2
	Red pine	3.356	-11.962	0.44	101	24.5
	Black spruce	3.736	-20.555	0.84	9	24.8
	White spruce	3.278	-14.364	0.36	83	24.2
	Balsam fir	3.208	-12.261	0.29	101	17.7
	Aspen/poplar	3.367	-9.675	0.24	361	26.2
	White birch	3.325	-9.980	0.22	224	23.0
	Yellow birch	2.989	-6.005	0.90	6	17.0
	Maple spp.	3.214	-8.455	1.14	299	24.0
	Beech	3.062	-7.215	0.57	19	18.0
	Oak	3.001	-7.683	0.46	64	21.0

[1]Standard error of estimate
[2]Sample size

Stratum	Species	Coefficients a	Coefficients b	SEE[1]	N[2]	Max height (m)
5. Pine, aspen birch	White pine	3.549	-14.958	0.21	465	29.0
	Red pine	3.434	-13.617	0.40	106	26.0
	Jack pine	3.320	-14.350	0.99	8	20.0
	Black spruce	3.176	-12.836	0.29	7	15.0
	White spruce	3.380	-15.685	0.23	130	23.5
	Balsam fir	3.326	-12.881	0.27	86	19.0
	E. white cedar	3.405	-23.931	1.40	7	17.0
	Aspen/poplar	3.479	-11.354	0.46	84	34.0
	White birch	3.091	-5.649	0.31	106	21.0
	Yellow birch	3.153	-13.002	0.72	8	17.0
	Maple spp.	3.182	-9.616	0.26	166	22.0
	Black ash	3.137	-12.683	1.20	5	170
	Basswood	3.128	-8.648	-	4	17.0
	Oak	2.948	-7.344	0.69	39	18.0
6. Pine, oak	White pine	3.477	-14.375	0.21	454	33.5
	Red pine	3.354	-13.042	0.35	179	21.5
	Jack pine	2.873	-4.509	0.55	9	16.7
	Black spruce	3.765	-23.527	1.00	8	19.8
	White spruce	3.390	-15.915	0.37	76	28.5
	Balsam fir	3.272	-12.118	0.43	27	21.0
	Aspen/poplar	3.291	-9.940	0.45	65	23.0
	White birch	3.142	-7.482	0.46	49	23.0
	Maple spp.	3.062	-8.474	0.26	262	25.0
	Black ash	2.673	-2.848	1.01	8	18.5
	Oak	3.125	-10.807	0.19	458	22.5
7. Cedar, ash, spruce	Black spruce	3.608	-15.735	0.69	16	23.0
	E. white cedar	3.060	-10.865	0.68	32	19.0
	Ash	2.844	-4.100	0.54	44	17.0
8. Other mixed-woods	White pine	3.632	-16.871	0.56	53	35.1
	White spruce	3.310	-16.791	0.41	45	20.6
	Balsam fir	3.201	-11.196	0.51	19	17.5
	Aspen/poplar	3.415	-11.584	0.44	66	24.5
	White birch	3.065	-10.572	0.54	29	16.9
	Maple	3.246	-10.517	0.41	116	20.0
	Oak	2.994	-8.755	0.71	26	20.0
9. Maple, birch	White pine	3.405	-12.732	0.69	25	25.8
	White spruce	3.788	-22.115	1.08	6	25.0
	Balsam fir	3.297	-10.396	0.41	13	18.0
	Eastern hemlock	2.705	-5.454	1.09	8	17.0
	Aspen/poplar	3.252	-7.928	0.42	15	23.0
	White birch	3.105	-6.143	0.65	36	21.0
	Maple spp.	3.161	-8.850	0.51	96	21.0

Stratum	Species	Coefficients a	Coefficients b	SEE[1]	N[2]	Max height (m)
10. Oak	White pine	3.209	-13.656	0.32	189	25.0
	Red pine	3.004	-7.261	1.01	15	20.2
	Black spruce	3.632	-15.783	0.85	19	23.3
	White spruce	2.909	-12.053	0.55	40	17.2
	Aspen/poplar	3.417	-11.845	0.33	126	25.3
	White birch	3.261	-8.860	0.30	65	22.0
	Maple spp.	3.380	-12.633	0.30	249	19.0
	Ash spp.	3.007	-7.643	0.53	10	19.0
	Oak	3.110	-10.952	0.14	705	20.0
11. Aspen	White pine	3.287	-13.109	0.46	71	29.7
	Red pine	3.134	-11.351	0.30	45	24.0
	White spruce	2.863	-9.514	0.50	4	20.5
	Aspen/poplar	3.327	-8.206	0.18	451	24.2
	White birch	3.233	-7.109	0.31	87	21.0
	Maple spp.	2.786	-5.050	0.26	134	17.5
	White ash	3.143	-6.799	-	3	21.0
	Black ash	3.230	-8.894	0.52	18	17.5
	Oak	3.126	-8.768	0.38	68	21.2
12. Birch	White pine	3.003	-12.434	0.61	11	13.0
	White spruce	3.421	-20.870	0.72	12	19.5
	Aspen/poplar	3.443	-11.739	0.49	17	27.0
	White birch	3.234	-8.263	0.42	61	25.0
	Maple spp.	3.017	-6.433	0.51	77	23.0
	Black ash	3.183	-9.642	0.98	10	19.3
	Oak	3.475	-20.825	0.70	16	22.0
13. Other hard-woods	Beech	3.182	-7.844	1.10	42	20.3
	Oak	3.072	-5.529	0.78	12	20.0
14. All areas (average)	White pine	3.443	-15.125	0.05	1825	35.1
	Red pine	3.395	-13.281	0.05	616	28.0
	Jack pine	3.209	-11.758	0.11	126	22.0
	Black spruce	3.520	-16.094	0.17	139	24.8
	White spruce	3.513	-17.376	0.08	524	28.5
	Balsam fir	3.152	-10.924	0.06	395	21.0
	Larch	2.991	-7.182	0.24	58	17.0
	E. white cedar	3.075	-13.299	0.21	76	19.0
	Eastern hemlock	2.705	-5.454	1.02	9	17.0
	Aspen/poplar	3.337	-9.341	0.06	1342	26.0
	White birch	3.280	-9.964	0.09	751	23.0
	Yellow birch	3.262	-13.837	0.40	36	18.0
	Maple spp.	3.310	-10.764	0.05	1540	25.0
	Ash spp.	3.001	-7.643	0.13	126	21.0
	Basswood	3.128	-8.648	0.65	33	23.0
	Beech	3.071	-7.073	9.32	67	25.0
	Oak	3.055	-9.569	0.05	1422	-
	Other hardwoods	3.000	-8.000	-	153	-

Appendix 5

Simple Random Sampling Formulae

1. Mean volume per plot for each stratum or type

$$\bar{y} = \frac{1}{n} \sum y_i$$

where $\bar{y}$ = mean volume of stratum or type (m^3 per plot)
n = number of plots in stratum or type
y_i = volume of plot i (m^3)

2. Standard error of estimate for each stratum or type

$$s^2 = \frac{1}{n-1} \sum (y_i - \bar{y})^2 = \frac{1}{n-1} \left(\sum y_i^2 - \frac{(\sum y_i)^2}{n} \right)$$

s^2 = variance of stratum or type

where $s(\bar{y}) = \sqrt{s^2/n}$
= standard error of estimate of $\bar{y}$ (m^3)
$se\% = 100\ s(\bar{y})/\bar{y}$
= standard error of estimate of $\bar{y}$ (%)

3. Total Volumes for each stratum or type

$Y = 25\ \bar{y}\ A$ where A = area of stratum or age (ha)

= total volume of stratum or type

Note: Use of these formulae assumes that the finite population correction factor is negligible, and that plot size is 1/25 ha or 400 m^2.

Appendix 6

Example of Permanent Sample Plot data

1. Main plot (400 m²)

Plot no.	Disturbance	Stand no.	Stratum no.	Tree no.	Tree condition	Tree status	Tree species	1980 dbh (cm)	1980 Ht. (m)	1980 V_t (m^3)	1980 V_m (m^3)	1985 dbh (cm)	1985 Ht. (m)	1985 V_t (m^3)	1985 V_m (m^3)
31	7	482	6	1	3	1	710	12.7	14.1	.080	.064	12.7	14.1	.079	.063
				2	3	1	800	9.2	12.2	.034	-	9.8	12.5	.040	-
				3	3	1	983	11.7	10.3	.052	.043	12.0	10.6	.056	.047
				4	1	1	20	28.0	20.7	.559	.536	30.7	21.6	.698	.671
				5	2	1	20	18.6	16.2	.199	.186	18.6	16.2	.199	.186
				6	2	2	20	28.0	20.7	.559	.536	28.4	20.8	.579	.555
				7	3	4	970	8.1	4.1	.011	-	8.1	4.1	.011	-
				8	0	5	970	8.3	4.1	.011	-	8.3	4.1	.011	-
				9	3	1	800	10.9	12.9	.051	.041	11.9	13.3	.062	.052
				10	0	5	800	8.7	11.9	.030	-	8.9	12.0	.032	-

V_t = gross total volume
V_m = gross merchantable volume

Plot disturbance

Code	Name
1	Harvesting
2	Blowdown
3	Fire
4	Insects
5	Disease
6	Other
7	None
9	Missing

Tree condition

Code	Name
1	Healthy
2	Stem rot
3	Conks
4	Damaged
5	Dead

Tree status

Code	Name
1	Dominant
2	Codominant
3	Intermediate
4	Suppressed
5	Understorey

2. Sub-plot (100 m²)

Plot no.	Distur-bance	Stand no.	Stratum no.	Species	dbh class	Ht. (m)	1980 Frequency	1980 V	1985 Frequency	1985 V
31	7	482	6	970	1	1.3	4	.0002	7	.0004
				970	3	1.8	1	.0007	1	.0007
				970	5	2.8	2	.0057	2	.0057
				210	1	1.3	4	.0002	5	.0003
				210	3	1.8	1	.0007	1	.0007
				800	1	1.6	10	.0006	17	.0010
				800	3	5.7	3	.0054	3	.0054
				800	5	8.8	3	.0228	4	.0303
				800	7	10.8	1	.0178	0	-
				130	1	1.3	0	-	1	.0001

Frequency = no. of trees per class
V = gross total volume of all trees in class

dbh Class

Code	Range (cm)
1	0-2.0
3	2.1-4.0
5	4.1-6.0
7	6.1-8.0

Appendix 7

Example of Stock Table - projections to 1995.

Stratum: 1. - Pine
Species: White pine
Area: 1653 ha

DBH (cm)	1980 Inventory	1985 Inventory volume (m^3/ha)	----- Projections ---- 1990	1995
10-12	0.7	0.7	0.6	0.5
13-16	2.1	1.6	1.4	1.4
17-20	3.5	3.3	2.3	1.9
21-24	9.1	7.1	6.0	5.0
25-28	14.3	11.0	10.2	8.3
29-32	15.2	19.5	22.5	24.1
33-36	18.0	13.9	14.8	16.3
37-40	21.5	22.3	22.1	19.4
41-44	12.5	18.8	27.2	38.8
45-48	4.7	6.0	15.4	23.1
49-52	3.6	5.5	7.5	12.1
53-56	4.4	4.6	2.3	3.5
57-60	2.5	2.6	5.3	2.6
61-64	2.9	3.1	..	3.0
65-68	-	-	3.4	3.6
69-72	-	-	-	-
SUM:	115.2	120.0	141.0	163.5

Appendix 8

Volume predictions by forest types

Forest type	Area (ha)	1985 Volume Ave. (m^3/ha)	1985 Volume % (of total)	1995 Volume Ave. (m^3/ha)	1995 Volume % (of total)	Annual increment Ave. (m^3/ha·yr)	Annual increment % (of total)
Softwood	2237	211	12	257	12	4.6	13
Mixedwood	10830	229	64	273	64	4.4	61
Hardwood	5270	173	24	210	24	3.7	26
Total	18337	210	100	253	100	4.3	100